System Effects in Low-Carbon Electricity Systems

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Introduction

Recent fast deployment of subsidised Variable Renewable Energy (VRE) had a significant impact on the whole electricity systems in many OECD countries.

Tech and Eco

- Increasing needs for T&D infrastructure, challenges for balancing.
- Significant impacts on the mode of operation and flexibility requirements of conventional power plants in both the short- and long-run.
- Large effects on the electricity markets (lower prices, higher volatility) and on the economics of existing power plants.

Analysis

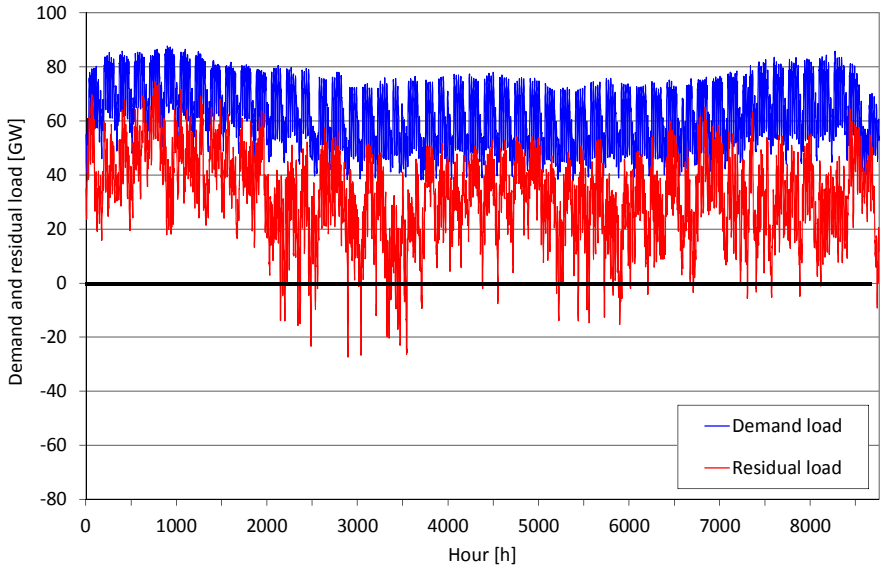
- Traditional metrics such as the LCOE are not sufficient anymore to adequately characterise and compare different generation sources.
- Need to look at the electricity system as a whole and not at each component in isolation.

Increasing attention has been given to the definition, analysis and quantification of system effects and costs (*integration costs*) in the scientific literature and in the policymaking areas.

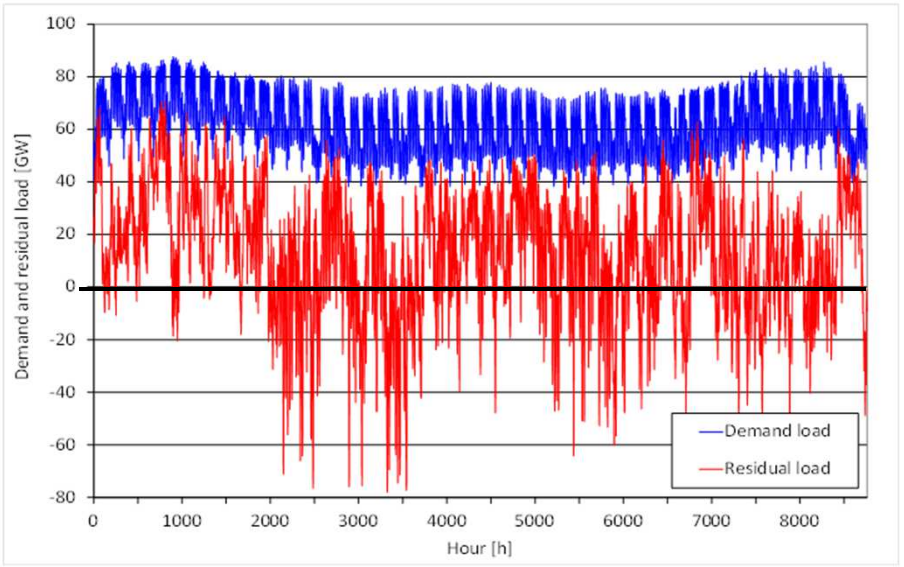
Impact on the Residual Demand Load

- Quantitative analyses performed by IER Stuttgard based on very detailed modelling of the German electricity system. Twelve scenarios, with 4 shares of VRE generation.

50% Renewables scenario (35% of VRE)



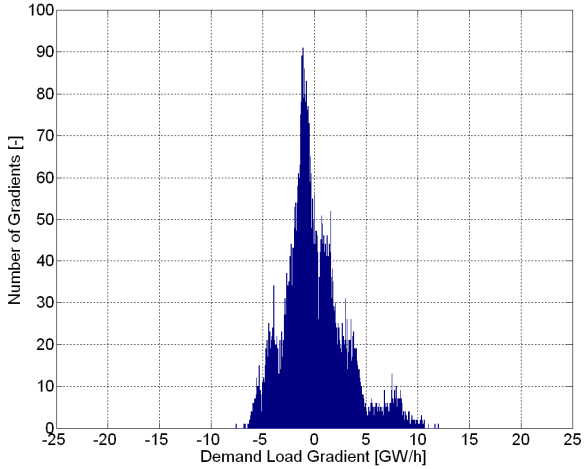
80% Renewables scenario (62% of VRE)



- Residual demand load is determined more by the production of VRE than by the demand.
- Residual demand load loses its characteristics seasonal and daily patterns.
  - More difficult to plan a periodic load-following schedule.
  - Loss of predictable peak/off-peak pattern (ex: impact of PV and effect on hydro-reservoir economics).
- Significant number of hours in which Renewables fully meet the demand.

Flexibility Requirements: Ramping Rates

15% Res scenario (0% of VaRen)



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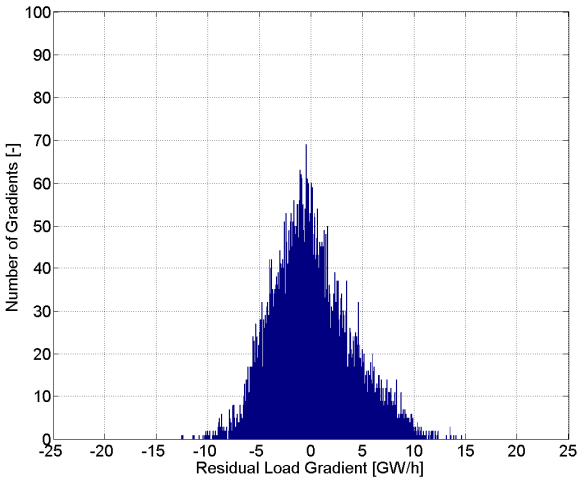

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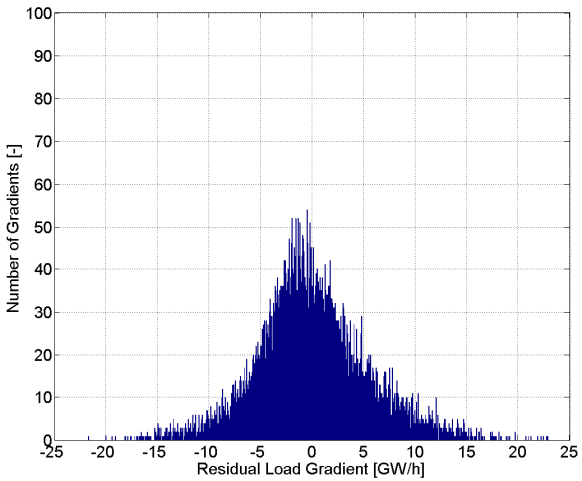
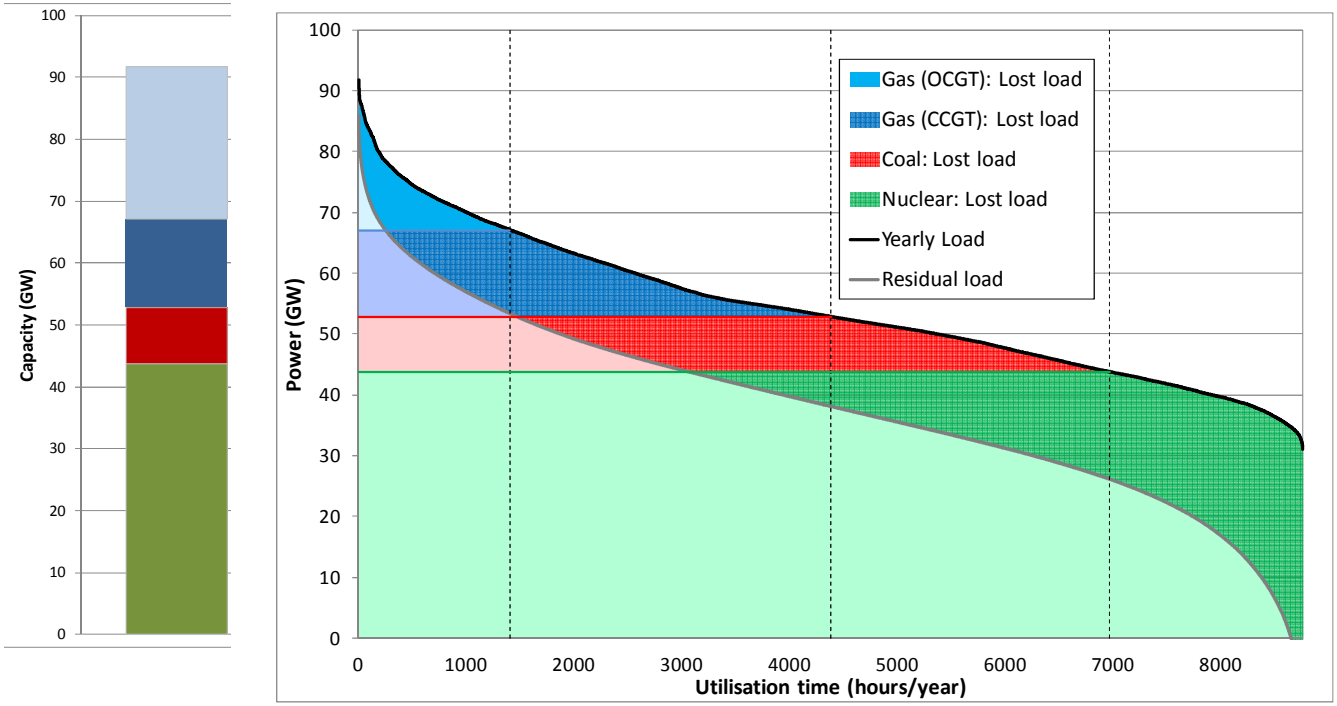


- High gradient of change in residual load (more than 20 GW/h, about 25% of maximal load !)
- Those changes must be assured by a reduced number of dispatchable generators.
- The unpredictability of those changes adds an additional difficulty to the challenge.

➡ More and more flexibility will be required from **all** components of electricity system.

- Significant load-following will be required from all dispatchable generators including base-load.
- Large amounts of storage capacity required at high penetration level of VRE.
- Curtailment of VRE or Demand Side Management are the most cost-effective solution.

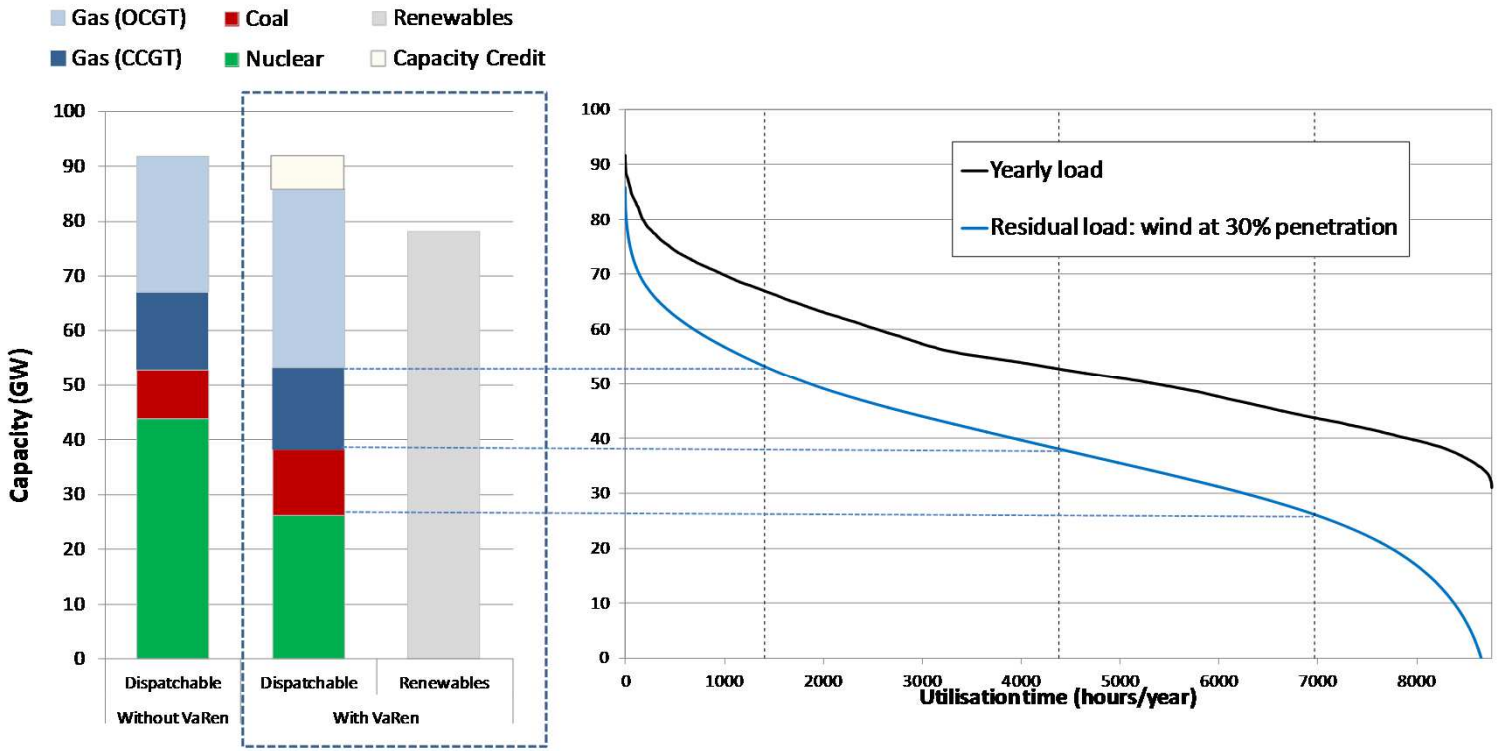
Short-run impacts



In the ***short-run***, renewables with zero marginal costs replace technologies with higher marginal costs, including nuclear as well as gas and coal plants. This means:

- Reductions in electricity produced by dispatchable PP (lower load factors, *compression effect*).
- Reduction in the average electricity price on wholesale power markets (*merit order effect)*.
- Declining profitability especially for OCGT and CCGT (nuclear less affected).
- No sufficient economical incentives to built new power plants.

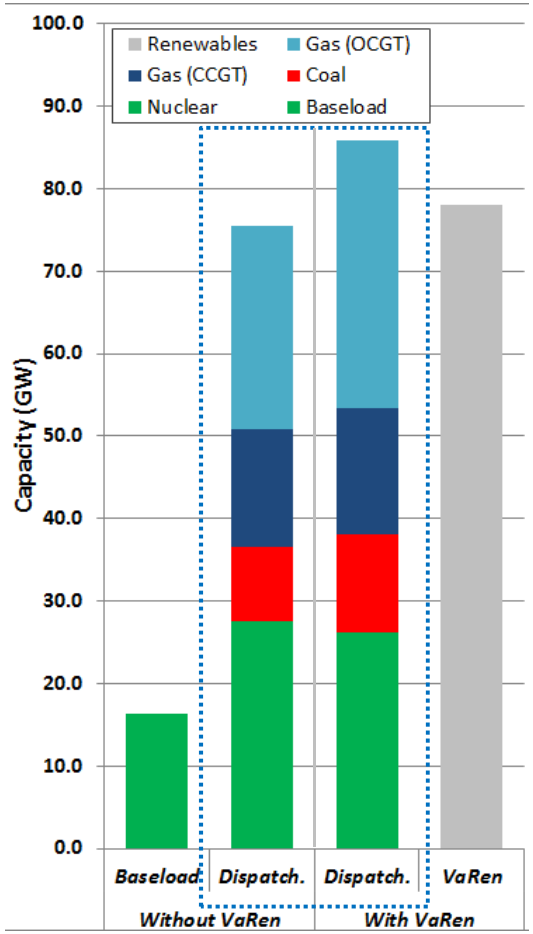
Long-run impacts on the optimal generation mix

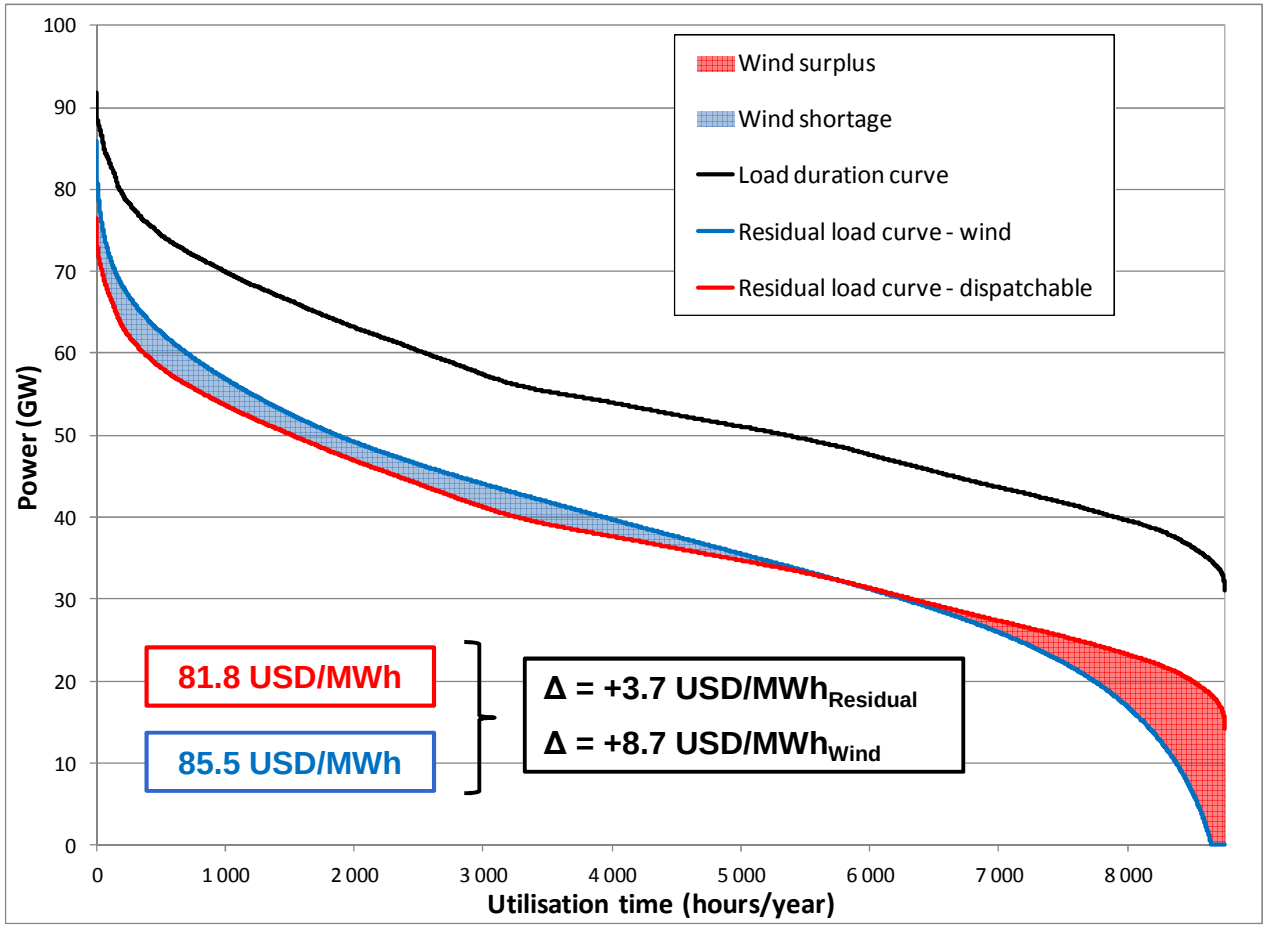


- Production from VRE will change generation structure for the residual system.
- Renewables will displace base-load on more than a one-to-one basis, especially at high penetration levels: base-load is replaced by wind and gas/coal (more carbon intensive).
- Cost for residual load will rise as technologies more expensive per MWh are used.
- These effects (and costs) **increase substantially** with penetration level.

Quantification of profile costs

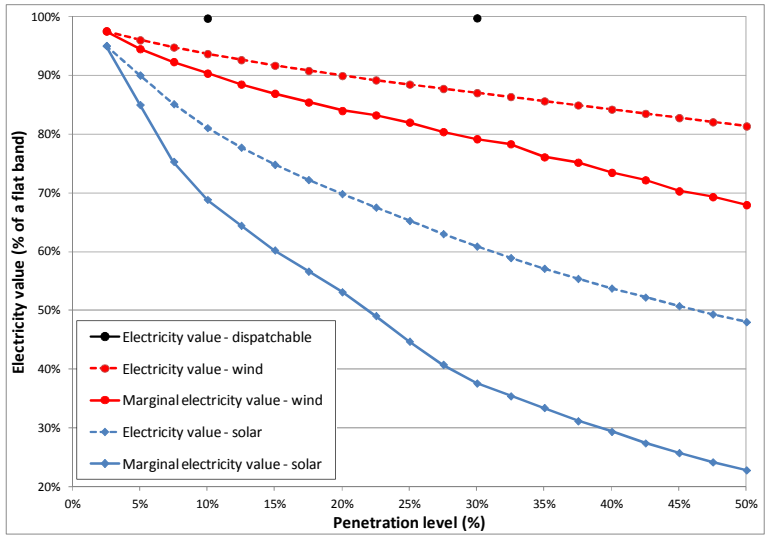
We compare two situations: the residual load duration curve for a 30% penetration of fluctuating wind (blue curve) and 30% penetration of a dispatchable technology (red curve).

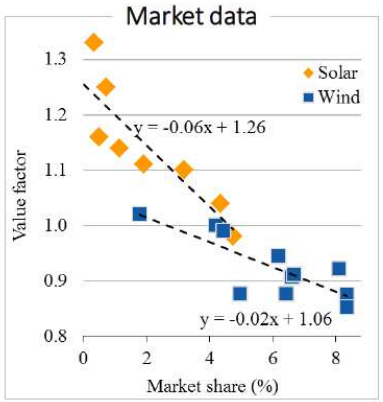


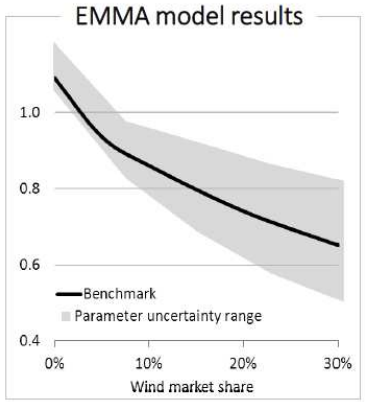


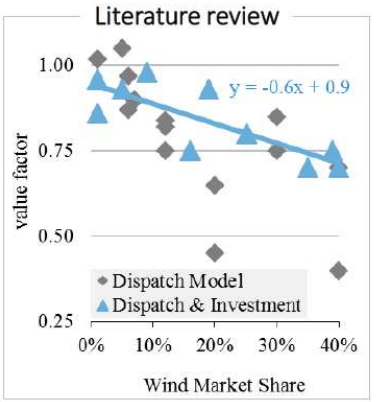
Declining Value of VRE Contribution

- The auto-correlation of VRE production reduces the its effective contribution to the system and thus its **market value** at increasing penetration level.









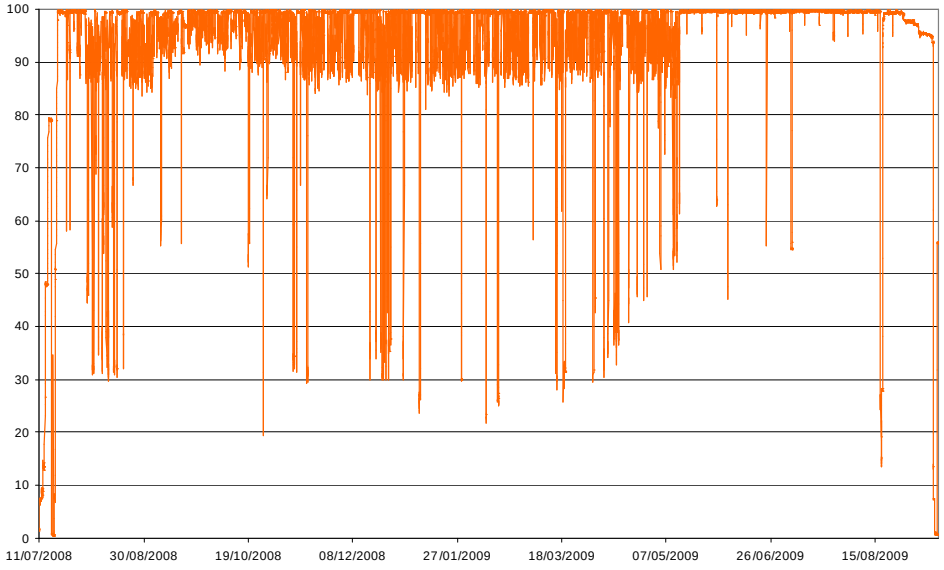
Source: Lion Hirth

- Wind value factor drops from 1.1 at zero market share to about 0.5 at 30% (*merit-order* effect)
- Solar value factor drops even quicker to 0.5 at only 15% market share
- Existing capital stock interacts with VRE: systems with much base load capacity feature steeper drop

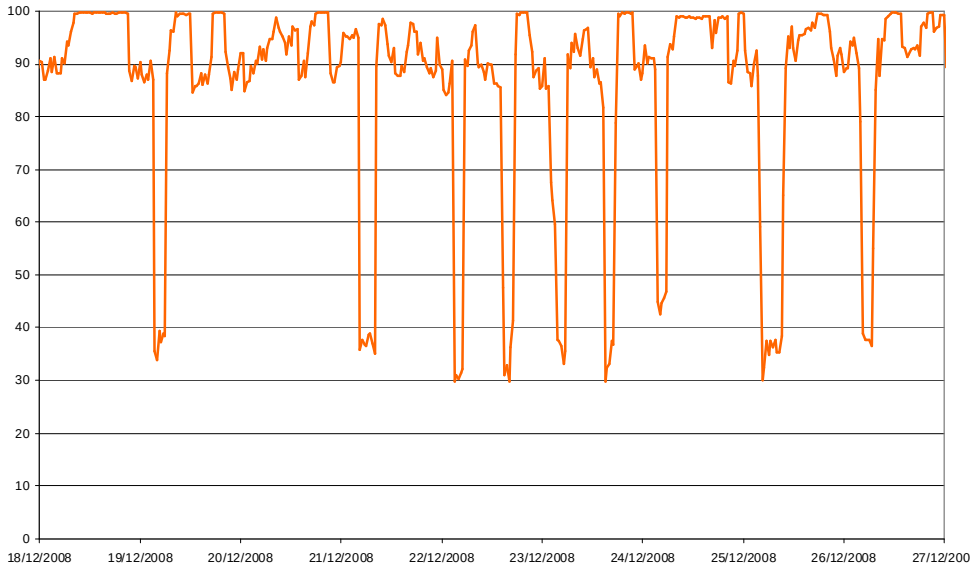
Flexibility of nuclear power plants: an example from France

- ***In some countries (France, Germany, Belgium) significant flexibility is required from NPPs:***
  - Primary and secondary frequency control.
  - Daily and weekly load-following.

Power history of a French PWR reactor



Whole cycle



10-day period around Christmas

- For 2/3 of the cycle the load fluctuates between 85% and 100%, while in the last third of the cycle the plant is operated in a base load mode.
- Daily load following, with power reductions up to 35%-40% of nominal power.
- “Stretch” can be observed in the last few days of operation.

Contribution to reduce system effects: flexibility of nuclear power plants (II)

- Flexibility of nuclear power plants has constantly improved over time.
  - Several Gen II plants were already built with sufficient manoeuvring capabilities or have been already upgraded
  - Strong flexibility is required by utilities and already implemented in the design of new Gen III NPPs

	Start-up Time	*Maximal change in 30 sec*	*Maximum ramp rate (%/min)*
Open cycle gas turbine (OGT)	10-20 min	20-30 %	20 %/min
Combined cycle gas turbine (CCGT)	30-60 min	10-20 %	5-10 %/min
Coal plant	1-10 hours	5-10 %	1-5 %/min
Nuclear power plant	2 hours - 2 days	up to 5%	1-5 %/min

- ***Economic impact of significant flexibility from NPPs***
  - No proven impacts on fuel failures and major components.
  - Studies have shown correlation between load following and increased maintenance needs, but were unable to quantify the related costs.
  - EdF has observed a reduction in availability factor due to extended maintenance (1.2-1.8%).
  - The main economic consequence of load following is the load factor reduction.

Key points and takeaway messages

- **The NEA study on system effect was pioneering and has contributed to progress in the area**
- **Increasing attention is given on the topic in the scientific literature and policy-making areas**
  - ✓ Work at the IEA on the integration of VRE.
  - ✓ An in-depth analysis of the large VRE integration at an EU scale from the French utility EdF.
  - ✓ NEA is undertaking a follow-up of the System Cost study.
- **Different effects in the short-run and the long-run**
  - ✓ VRE displace peakers in the short-run and base-load technologies in the long-run.
  - ✓ Effect on average market price is transitory: market prices will have to go back to long-term average cost recovery. However more volatility is to be expected.
  - ✓ The impact on CO2 emissions in the long-run.
- **System costs are country-specific, strongly interrelated and depend on penetration level**
  - ✓ Integrating the first 10% of intermittent resources do not pose the same economic and technical challenges as increasing penetration level from 20 to 30%.
  - ✓ What is the technical and economic limit to the integration of VRE?
- **The value of VRE generation decreases drastically with penetration level**
  - ✓ This affect both the market value (private) and the system value (social).
- **System costs are large and need to be appropriately accounted for and internalised**

Thank you
For your attention

The NEA reports are available on-line

"System Cost"	http://www.oecd-nea.org/ndd/pubs/2012/7056-system-effects.pdf
"Nuclear new built"	http://www.oecd-nea.org/ndd/pubs/2015/7195-nn-build-2015.pdf
"Load Following"	http://www.oecd-nea.org/ndd/reports/2011/load-following-npp.pdf
"The EdF study"	http://www.energypost.eu/wp-content/uploads/2015/06/EDF-study-for-download-on-EP.pdf

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